Figure 1. Young slash pine plantation immediately after a severe wildfire. The litter was consumed, all hardwoods were killed back to ground level, and the pine crowns were completely scorched.

Management Decisions In Severely Damaged Stands

Dale D. Wade and Darold E. Ward

ABSTRACT—After a timber stand has been severely damaged, management options can be evaluated by comparing rates of return on investment. All important factors should be assigned values. When the likelihood of recovery is uncertain, it often pays to delay the decision.

After wildfire, insects, disease, ice or wind severely damage a stand of trees, a forester must decide whether to restock the area or to manage the remaining trees. A comparison of rates of return on investment is a sound basis for such a decision only if all the important factors are included in the analysis. To compute rates of return, the forester must estimate mortality and growth loss, as well as the costs and risks associated with the alternatives.

We present some post-disaster stand management options that should be considered in choosing the alternative that will best fulfill the management objectives. We use a slash pine (*Pinus elliottii* Engelm.) plantation heavily damaged by wildfire at age 5 as an example of how such an assessment might be made using simple, economic theory.

Stand History

This 55-acre plantation was established in the South Carolina sandhills during the spring of 1962 after mechanical preparation of a site occupied by scrub oak (*Quercus* spp.). The one-year-old stock was planted on an 8- by 8-foot spacing (680 trees per acre). Site index was estimated to be 50 feet at age 25. An understory of herbaceous plants and low-value hardwoods (mainly *Andropogon* spp. and *Quercus* spp.) had developed by April 1966. At that time, the planted pines averaged 8 feet in height and slightly less than 1 inch dbh. A thin layer of needles and leaves contributed little to the total fuel complex, which was estimated at 6.3 tons (ovendry weight) per acre.

On the afternoon of April 1, a wildfire that has been described in detail elsewhere (*3, 5*) swept very rapidly across the plantation. There was a lack of heavy, slow-burning dead fuels, but high winds produced an intense, fast-moving fire. A damage survey revealed that almost all pine needles were scorched, but that relatively few needles had been consumed (*Figure 1*). Many of the smaller pine branches and needles were desiccated and stiffened horizontally in the direction of fire spread. When the fire struck, the pines were undergoing their annual burst of rapid height growth, and it appeared that the unprotected meristematic tissues on most branches had been killed. Thus, it was feared that the plantation might be a total loss.

Management Alternatives

Should the area be replanted or some other remedial action be taken? To compute a rate of return for an investment option, it is necessary to know both the costs and returns associated with that option. A forest manager must examine, among other alternatives, the

Reprinted from the JOURNAL OF AMERICAN FORESTRY
Vol. 73, No. 9 September, 1975

possibility of retaining the existing stand based on the costs for its establishment and continued management. When he is considering liquidating the old stand and planting a new one, the establishment costs for the damaged stand must be added to those for the new stand. Each cost, of course, must be compounded from the time it was incurred until the time when returns are received.

Normally, the most difficult item to estimate soon after a stand has been severely damaged is the yield that can be expected if that stand is carried through to rotation age. In this determination, there is no substitute for a systematic survey of the stand and a careful examination of available information on the probable responses of the trees.

The literature on slash pine fire damage reveals that the chances for survival with 100 percent scorch and no needle consumption are excellent (*7, 8, 9*), but that a temporary reduction in growth should be anticipated. Lindenmuth et al. (*6*) relate damage to burning index at the time of the fire. A call to the county unit revealed that in our case it was at 100, its maximum value, on April 1. Further, U.S. Weather Bureau records from a nearby station showed that while the February rainfall was slightly above average, only about 50 percent of the 4-inch March norm was recorded, and all but 0.14 inch of that amount fell before March 5. Thus, moisture was severely deficient on this sandhill site where the infiltration rate is generally high and soil water-holding capacity low. These two factors, along with the unseasonably high temperature (86° F.) the day of the fire, suggested that damage might be greater than normally expected.

The decision to restock a site or carry the residual stand to maturity after a wildfire is complicated by a number of practical considerations. Replanting has to be programmed into the work schedule. Variables such as site productivity and availability of planting stock have to be assessed before adjusting planting priorities. Economics and valuation of the fire-damaged stand must be weighed against the costs and risks associated with replanting. In our example, probable rate of return from management of the existing stand could not be reliably calculated immediately after the fire because it was impossible to estimate the extent of mortality. The area could be replanted immediately, but summer planting success is unpredictable.

Armed with such scanty information and his experience, the forest manager must pick one of the following alternatives: go with the survivors; interplant; replant; or put off the decision until a later date. The procedure described below should make this decision easier; it maximizes rate of return from the various alternatives based on capital invested and expected income.

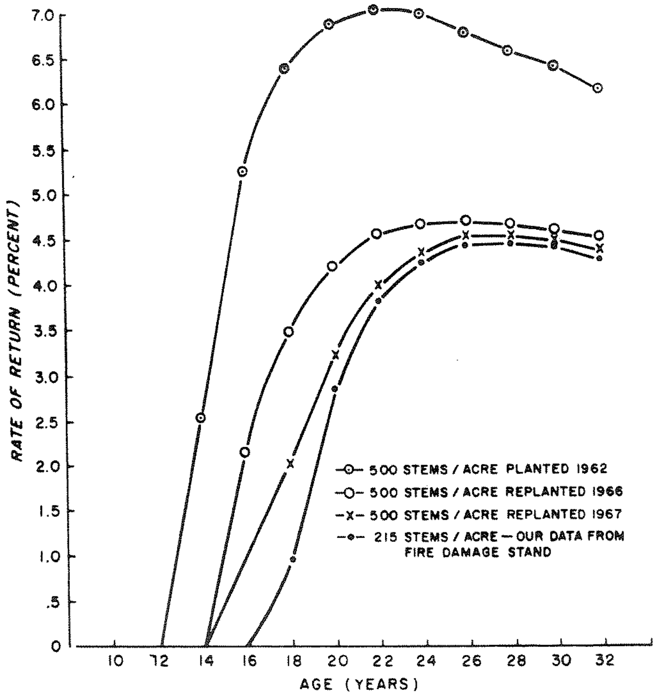


Figure 2. Rates of return at selected harvest ages and stocking rates with a site index of 50.

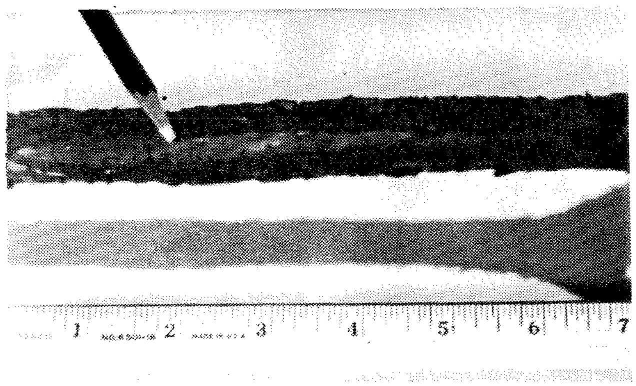
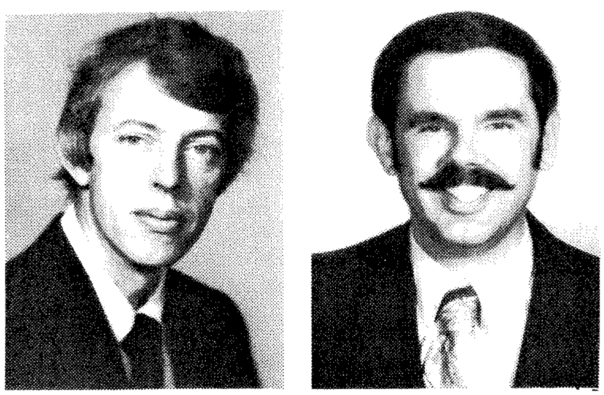


Figure 3. Terminal leader damage resulting from the wildfire. Note callus tissue formation.



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Evaluation Procedure

Probable yields at various harvest ages for a site index of 50 were taken from Bennett's tables (*2*). These values may be slightly high for sandhill sites, but they are sufficiently accurate for illustration. Under the assumption that original and final land values were equal, and that wood would sell for $10 per cord, the income at harvest can be calculated using the following equation:

$$\text{income} = (c)\,(w)$$

where, c = cords per acre at harvest from yield tables
w = wood value per cord.

Costs are computed as follows:

$$\text{cost} = V_o(1 + i)^n + \frac{a[(1 + i)^n - 1]}{i} + R$$

where, V_o = cost of site preparation and planting the original stand ($30 per acre)
1 = the unit of principal invested and receiving interest
i = rate of interest expressed as a decimal
n = the number of interest-bearing periods (generally years)
a = taxes and administration ($1 per acre per year)
R = $V_x(1 + i_x)^{n\,x}$ = cost to be added if the stand is replanted after the wildfire
V_x = cost of site preparation and planting the second stand ($15 per acre).

Do not be overwhelmed by this formula. Compound interest tables that give computed values of $(1 + i)^n$ and $\frac{(1 + i)^n - 1}{i}$ are readily available in such places as the *Forestry Handbook* (*4*, Tables 1A and 1C).

These costs and anticipated incomes can be combined to determine the rate of return for various rotations and compared to determine the rotation age that will maximize rate of return on the investment (*Figure 2*). The combined formula is:

$$[V_o(1 + i)^n] + \left[\frac{a[(1 + i)^n - 1]}{i}\right] + R = (c)\,(w)$$

A precise answer requires a series of mathematical approximations, but an acceptable answer can easily be obtained by the following procedure. Choose a rotation age and a stand density, and then compute (c)(w). Choose the two interest rates in appropriate tables that will give an answer that brackets the value just computed for (c)(w). Your rate of return will fall between these two values and interpolation will give a value very close to the true rate of return.

For example, the rate of return from this plantation at age 22 if replanted the spring after the wildfire (5 years after the original planting) would be:

$$[30(1 + i)^{27}] + \left[\frac{1[(1 + i)^{27} - 1]}{i}\right] + [15(1 + i)^{22}] = 182$$

where, (c) (w) = (18.2) (10) = $182.

Using *Forestry Handbook* tables (*4*) at 4.0 and 4.5 percent yields the following values:

4 percent—30(2.883) + 1(47.08) + 15(2.370) = $169.12
4.5 percent—30(3.282) + 1(50.71) + 15(2.634) = $188.68.

Since 182 is between 169 and 189, the rate of return is between 4 and 4.5 percent. Interpolation gives a figure of 4.3 percent.

Replanting immediately after the fire rather than waiting until the next spring would yield a rate of return of 4.5 percent at age 22. Thus, if the forest manager postpones his decision until the following winter and still decides to replant, his rate of return only drops two-tenths of a percent (*Figure 2*). Moreover, this short wait has enabled him to determine survival, distribution, and first-year growth reduction in the fire-damaged stand. He is now in a position to estimate growth recovery and yield from his original stand and compare these predictions against those made with a replanted stand. It must be emphasized that no risk factors are included in these calculations.

What Happened

Our example plantation was inspected again a year after the wildfire. The results surprised us. More than 70 percent of the pines occupying the site at the time of the fire were still alive. The cambium had been killed on the lee side of many of the stems, but callus growth was rapidly covering the wounds (*Figure 3*). The terminal leader died on most of these trees, but a new flush of needles and axillary buds developed further down the stem. The crowns had a broomed appearance on about 15 percent of the survivors (*Figure 4*). Brooming may have been caused by failure of one of the new shoots to establish apical dominance, or possibly by some pathogen.

Insect activity in the plantation was obvious. Pales weevils (*Hylobius pales* (herbst.)) had invaded the area from an adjacent salvage operation and tip moth larvae, probably of the Nantucket pine moth (*Rhyacionia frustrana* (Comst.)), were feeding on the new pine growth.

To help assess stand conditions, sample plots should be established at this time and the trees divided into vigor classes such as the following:

Vigor class 1—no noticeable damage.
Vigor class 2—terminal leader killed but replaced; rapid cambial healing.
Vigor class 3—trees broomed but healthy; rapid cambial healing.
Vigor class 4—poor crown development; little chance for survival.
Vigor class 5—dead.

Actual growth reduction caused by the fire can be determined by cutting a few trees in each vigor class.

Based on our survey, it was decided that most of the trees would probably not succumb to the insect attack or effects of brooming. But continued retardation of height growth was expected for several more years. Future mortality was estimated at 15 percent. Ex-

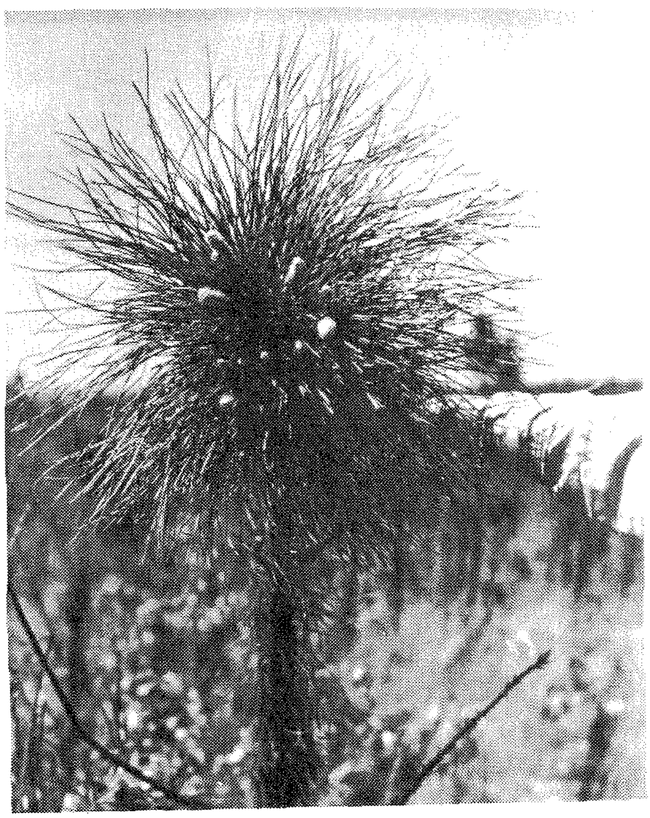

Figure 4. Brooming of young slash pine following death of the terminal leader. Photograph taken 1 year after the wildfire.

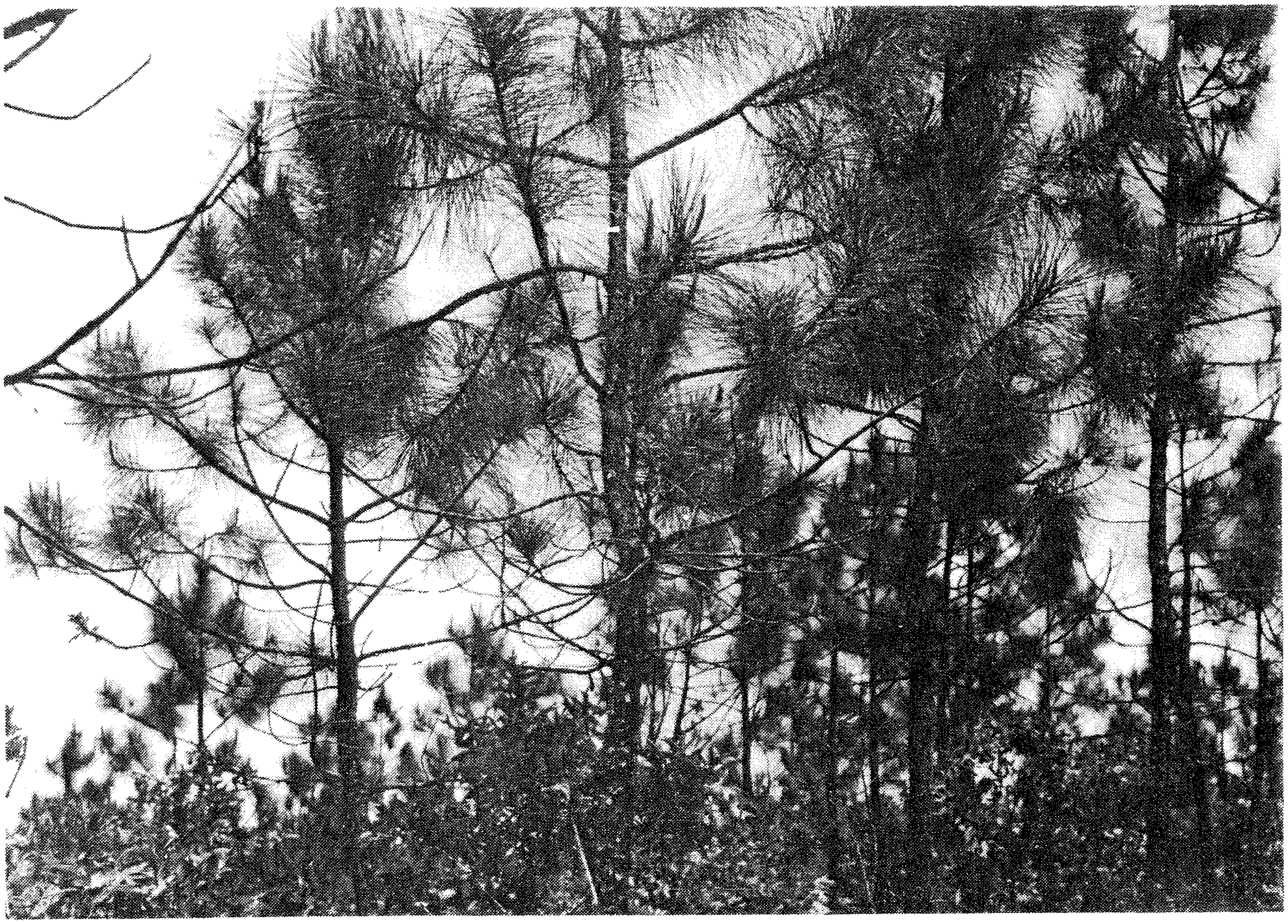

Figure 5. Slash pine plantation 7 years after a severe wildfire showing understory buildup and crooks in pine stems resulting from death of the terminal leaders.

pected returns at various harvest ages were then computed for the survivors (*Figure 2*). Loss in growth was accounted for by reducing the number of cords produced Computation indicated a maximum rate of return of 4.5 percent would be realized at age 28.

The forest manager was now in a much better position to make his decision than he was immediately after the fire. He could compare projected returns from his alternatives and decide whether the difference between returns was great enough to warrant replanting. Because interplanted slash pines generally exhibit poor survival and growth (*1*), this alternative was discarded without further consideration. In this case, the landowner elected to keep his expenditures at a minimum and rely upon the survivors to provide an acceptable return.

The stand was examined again seven years after the fire to assess its progress during the preceding six years, as well as its future potential (*Figure 5*). Mensurational data collected are summarized in *Table 1*.

We selected several trees for a rigorous analysis of diameter and height growth (*Figures 6, 7*). Both diameter and height growth were significantly reduced by the fire, but they have slowly improved since. No loss of revenue is anticipated because of internal defect or tree form from trees in vigor classes 1 or 2. However, class 3 trees are smaller than those in classes 1 and 2 and, thus, will produce correspondingly less merchantable wood. Class 4 trees may not survive until harvest.

Making the Choice

Whether the old stand should or should not have been liquidated after one year is open to discussion. The 4.5 percent rate of return (*Figure 2*) from replanting is by no means guaranteed. As the first fire demonstrated, a young slash pine plantation is subject to heavy losses. Droughts and insect and disease attacks are also possibilities. In our example plantation, mortality was observed to be rather evenly distributed and provided increased growing space to the survivors. The result may be larger-than-average trees and higher-than-average stumpage prices at harvest time. For most investors, the additional returns from replanting probably would not be worth the additional risks.

On industrial forest lands where optimizing wood production is a major objective, the choice might be to replant. Even on industry lands, however, this choice is not clear-cut because some sites are not highly productive. On land with a site index of 70, for example, replanting would have yielded a maximum rate of return of 8.6 percent after 22 years and replanting would have been an attractive choice.

From data collected one and seven years after the fire, then, it is difficult to quarrel with the manager's decision not to replant. And the key to his successful decision was a willingness to wait rather than to make a snap judgment.

Observations in the study plantation lead to several important conclusions:

Table 1. Stand mensurational data based on four 1/4-acre plots at age 12.

Vigor class[1]	Trees per acre	Average dbh	Average height	Average broom height	Range in broom height	Range in dbh	Range in height
	Number	*Inches*	*Feet*	*Feet*	*Feet*	*Inches*	*Feet*
1	141	3.87	21.2	—	—	2.4-4.9	9-30
2	25	2.96	16.7	8.2	5-12	1.5-3.7	9-21
3	21	2.75	12.8	9.1	5-13	1.4-3.3	8-17
4	43	2.59	11.4	8.8	6-15	1.2-4.5	7-18
5	(56)	—	—	—	—	—	—
Totals	230[2]	3.25	18.1	8.7	5-15	1.2-4.9	7-30

[1]*Vigor classes:*
1 = no noticeable defect
2 = slight crook in bole (indicates death of terminal leader at some previous time)
3 = tree broomed but healthy
4 = poor crown development—little chance of survival
5 = dead.

[2] *Excludes vigor class 5 but does include a few volunteer longleaf pine (*Pinus palustris *Mill.). They range from 1.2 to 5.8 inches dbh and from 4 to 30 feet in height.*

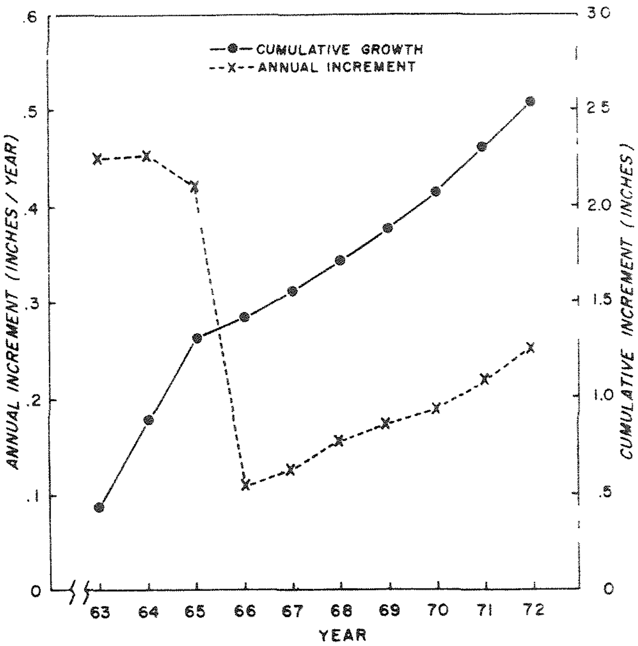

Figure 6. Average annual and cumulative diameter increment (inside bark) for six trees in vigor classes 1 and 2.

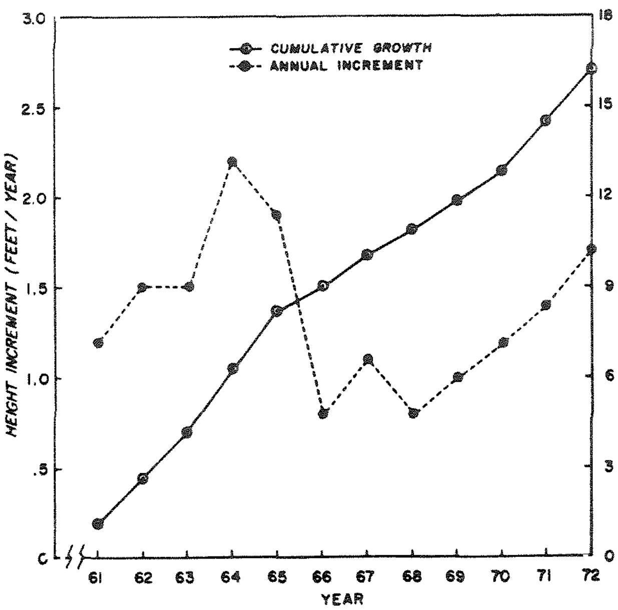

Figure 7. Average annual and cumulative height growth for six trees in vigor classes 1 and 2.

1. Young, healthy slash pines show a marked ability to recover from a fire even with 100 percent crown scorch and a drooping, obviously dead, terminal leader. As percentage of the crown scorched drops below 50 percent, the probability of death approaches zero. Consumption of more than 10 percent of the foliage, coupled with complete crown scorch, usually results in the death of the tree.

2. If there is little needle consumption, wait one growing season before deciding whether to replant. Direct fire mortality, as well as secondary disrupting agents, can be observed. Immediate fire effects often look worse than they actually are. The decrease in the expected rate of return by waiting one growing season is negligible—two-tenths of 1 percent in the illustration.

3. The land manager must understand and place a value on the risks associated with replanting and carrying a new stand to the age of the one presently occupying the site. Factors to be considered include the wildfire history of the area, ease of establishing nearby stands, likelihood of drought or other unfavorable weather conditions, current or predicted insect or disease infestations, and other simultaneous uses of the area such as for forage or wildlife.

4. Rate of return is strongly influenced by the productive potential of the site. Management alternatives are severely restricted on poor sites. ■

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